Endovascular Technique for Arterial Shunting to Prevent Intraoperative Ischemia

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WHAT THIS PAPER ADDS

Severe ischemia—reperfusion injury to the lower limb is a feared complication of prolonged vascular procedures and of acute conditions caused by sudden obstruction of arterial blood flow. This paper describes a novel and simple technique for arterial shunting to prevent intraoperative ischemia. The method is applicable in both endovascular and open surgical procedures.

Objectives: The use of an intraoperative shunt is an established technique used to reduce the ischemic time after acute arterial obstruction or in the prevention of hypoperfusion due to complex open vascular or endovascular operative procedures. To date, described methods of temporary extremity blood perfusion have required open surgical techniques.

Methods: An endovascular shunt (ES) was formed by connecting two introducer sheaths to each other, one positioned proximal and one distal to an arterial obstruction. The ES method was used in patients considered to be at high risk for prolonged lower limb ischemia in conjunction with a vascular procedure and where shunt creation by open surgical technique was not considered to be a practical alternative. The flow capacity of the ES was defined in a desktop model.

Results: The ES method was used clinically in 15 vascular interventions including eight complex endovascular aortic procedures, three open aortic operations, and four procedures for acute limb ischemia. The shunts were functional in all patients and there were no shunt occlusions. Postoperatively, there were no evident clinical reperfusion injuries. Flow analysis revealed that the ES had a flow capacity of 73% flow capacity compared to a Pruitt-Inahara shunt.

Conclusion: A new method of temporary blood shunting in connection to vascular procedures has been demonstrated.

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INTRODUCTION

Acute ischemia caused by a sudden obstruction of arterial blood flow can result in severe tissue damage. Common causes are trauma, thromboembolism, or arterial dissection. The ischemia and subsequent reperfusion can result in tissue necrosis, compartment syndrome, and transient or permanent nerve injury. In addition, reperfusion may cause systemic injuries to the heart, lung, and kidneys.[1,2] Permanent extremity injury can occur after 4—5 hours of ischemia,[3] and rapid restoration of flow is vital.[4] As vascular reconstructions may take several hours, temporary vascular shunts can be useful.[5,6]

Prolonged ischemia can also occur during elective complex vascular procedures. Large introducer sheaths may obstruct the ilieofemoral arteries during endovascular aortic repair (EVAR) and arterial clamping obstructs flow during open reconstructions.[7,8]

The concept of using an intraoperative arterial shunt to prevent prolonged ischemia is well established in open carotid and trauma surgery.[9,10] The use of temporary axillobifemoral bypass was recently described to prevent iatrogenic limb ischemia during complex fenestrated EVAR (FEVAR).[11] Until now, the methods described for temporary shunting have required open surgical techniques.

This report presents a new and simple method of arterial shunting using an endovascular technique.

METHODS

Technical description

An introducer positioned proximal to the arterial obstruction communicates with a second introducer positioned distal to the obstruction. The two introducers are connected

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by their side arms, either directly through an adapter or through extension tubing together with an adapter. The blood first enters the tip of the proximal introducer, flows through the sheath and out through the sidearm, continues via the connecting adapter or extension tube into the sidearm of the second introducer, and finally out through its sheath into the receiving artery.

If the shunting system is used to prevent ischemia caused by a large occluding introducer during a prolonged endovascular procedure, the blood can be deviated either from the obstructing introducer's side arm or from an introducer in the contralateral groin (Fig. 1). The second introducer is then placed in an antegrade position distal to the occluded segment either percutaneously or by cut-down technique, depending on which method is used for the endovascular aortic procedure. In this situation, the introducer hubs are in close proximity to each other, allowing the two side arms to be connected by a short male-to-male Luer—Lock adapter.

When the endovascular arterial shunt is used for acute ischemia caused by trauma or thromboembolism, the proximal introducer can be placed in an artery of an uninjured extremity. The distal introducer is again placed in an antegrade position distal to the occlusion. If the side arms are not close to one another, extension tubing bridges the distance between the introducers.

Material

The ES method used standard introducers (Super Sheath®; Boston Scientific, Natick, MA, USA) with side arms and Luer—Lock connections. A male-to-male adapter (Combifix® Adapter; Braun, Kronberg, Germany) was used to connect the female Luer—Lock connections of the introducers' side arms to each other. If the distance between the two introducers was too long, an extension tube was used (Perfucor® Tubing, Heidelberger Extension 30-cm Luer—Lock; Braun). In a select case, a shunt was also created by simply connecting the two introducers with a short piece of silicon tubing. This was introduced into the sidearm of the "donor" sheath and into the end-valve of the receiver sheath (7-F).

Clinical use

Data collected prospectively between March 2011 and March 2013 at the Vascular Center, Skåne University Hospital, Malmö, Sweden, and the Department of Vascular Surgery, Sahlgrenska University Hospital, Gothenburg, Sweden were analyzed retrospectively. The risk of intraoperative limb ischemia for patients undergoing endovascular aortic procedures was evaluated. During the study period, 607 endovascular aortic procedures were performed at the two vascular centers. Indication for the endovascular shunt (ES) method included procedures considered to have a high risk for lower limb ischemia due to obstruction of the access arteries for more than 3 hours. Probable occlusion was assumed when the sheath diameter was the same or nearly the same as the inner diameter of the access vessels. In these patients, the ES was established at the start of the procedure. During interventions with unexpectedly prolonged occlusion times, an extra-antegrade-positioned introducer was placed in the common femoral artery (CFA) or superficial femoral artery (SFA) after 4—5 hours. The ES method was also used in some patients with acute ischemia due to vascular trauma or aortic dissection. Only patients with ES were included in the study.

The anticoagulant regime was not altered by the use of an ES. For EVAR procedures, the heparin dose was titrated to result in an activated clotting time between 250 and 300 seconds. During open surgical operations, 2,500—5,000 IU heparin was given intraoperatively before arterial clamping.

The function of the shunt was verified by intermittent closure of one of the three-way stopcocks followed by injection of a small amount of saline into the transparent sidearm, and, finally, opening of the stopcock again. The visible effluence of clear saline confirmed a functioning shunt. Angiography through the shunt can also be used to control shunt function and to survey outflow vessels.

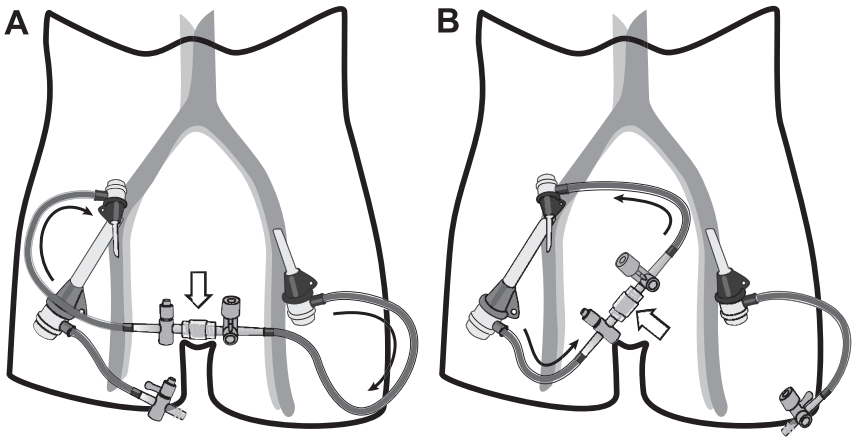

Figure 1. Illustrations of the endovascular shunt deviating blood from an introducer sheath from the (A) contralateral side and from a large introducer sheath in (B) the ipsilateral side. Blood runs through introducer side arms, interconnected by a male-to-male Luer—Lock adapter (open arrow). Arrows indicate flow direction.

Experimental flow measurement and inner diameter definition

The capacity of the ES was investigated in an experimental setup in which the flow was compared with a standard Pruitt–Inahara shunt (PIS). An intravenous (IV) bag with saline (0.9% sodium chloride) was used as a fluid reservoir. The PIS (Pruitt F3® Carotid Shunt, 9-F; LeMaitre, Burlington, MA, USA) was connected to the bag through its outlet port and was fixed in the port by inflation of the proximal balloon. A surgical clamp was used to occlude the shunt and control the flow. The ES (6-F and 8-F, 11 cm, Super Sheath®; Boston Scientific) was inserted through the membrane of the injection port of the same IV bag using the Seldinger technique. The side branch of a secondary introducer of the same size was connected to the first one by the male-to-male Luer–Lock adapter. Using this technique, both shunts were introduced into the fluid parallel to each other and sealed against the bag by their normal function. The IV bag was pressurized to 90 mmHg to mimic a physiological mean arterial pressure. The distal tip of the PIS and the ES were positioned at the same level 15 cm below the IV bag. The valve of the ES and the surgical clamp of the PIS were opened simultaneously. Flow through the two shunts continued for 1 minute, the fluid was collected into separate measuring cylinders, and the volume of flow per minute was defined.

The inner diameter of the different components of the introducer and the Luer Lock adapter was measured with a precision nozzle gauge.

RESULTS

Clinical cases

During the study period, ES was used in 11 planned procedures and in four emergency procedures for acute ischemia (Table 1; Supplementary Material).

The ES was established without technical failure in all patients. There was no bleeding due to the shunt and there were no shunt occlusions. Shunting time varied from 45 minutes to 8 hours.

Eight of the planned procedures were complex endovascular interventions with large introducers obstructing the CFA for long periods. These patients had an ES established by connecting the side arm of a retrograde ipsilateral or contralateral introducer to an antegrade introducer positioned distally in the CFA or the SFA of the occluded limb. In two patients the ES was established from the beginning; in the remaining six the shunt was placed when the duration of artery occlusion exceeded 3 hours.

In three patients with open surgical removal of infected aortic prostheses (two bifurcated stentgrafts after EVAR and one aorto-bifemoral graft after open repair), shunting with ES was used to perfuse the lower limbs in two cases and the kidneys in one case. In two of these patients, blood was taken from a percutaneously positioned retrograde introducer in the brachial artery.

There were no perioperative deaths in the planned vascular procedures, and no patient developed clinical signs of acute limb ischemia or kidney failure postoperatively (as indicated by an serum creatinine increase of >30% compared with baseline).

Two of the four patients with acute ischemia were caused by trauma. Two had aortic dissection extending into the iliac artery. In all four patients the ischemia was severe, including sensory loss and muscle weakness or paralysis. The acute ischemia was categorized as Rutherford IIb (see Supplementary Material). Immediate revascularization was considered necessary. After shunt placement, distal capillary filling returned in all patients. In this group, there were no deaths in conjunction with the procedures involving endovascular shunting. One patient with a type B dissection died during an open surgical aortic procedure the following day. Three patients had no extremity complications. One of the trauma patients, with complex pelvic and femoral fractures, had a femoral amputation 3 months after the acute surgical procedure. The reason for the amputation was healing problems, aggravated by pelvic venous obstruction.

The shunt blood flow was measured during three of the procedures, with a flowmeter over an isolated receiving SFA or directly over the ES tubing. The blood flow varied between 40 and 76 mL/min.

Experimental flow measurement and inner diameter definition

The experimental analyses showed that the flow capacity of 6- and 8-F ES was 64% and 73% of the PIS (Table 2), respectively, which demonstrates that the difference between the 6- and 8-F introducers had a minor influence on the shunt flow. The use of 8-F introducers increased the flow rate by 14%. A lengthening of the ES by a 30 cm extension tube caused a further reduction of the 6- and 8-F shunt flow to 36% and 45% of the PIS flow, respectively.

Table 1. Clinical practice of endovascular shunt (ES) in planned vascular procedures and in patients with acute limb ischemia.

Indication for ES	Patients (*n*)	Proximal introducer position (*n*)	Shunting time, mins, median (min.–max.)
Complex endovascular aortic repair	8	Ipsilateral CFA: 3 Contralateral CFA: 5	150 (60–480)
Open reconstruction for aortic graft infection	3	Brachial artery: 2 Contralateral CFA: 1	210 (45–225)
Acute lower limb ischemia due to trauma or aortic dissection	4	Brachial artery: 1 Contralateral CFA: 3	255 (120–473)

Common femoral artery (CFA).

Table 2. Experimental volume flow analyses of the endovascular shunt (ES) and the Pruitt–Inahara shunt (PIS).

Type of endovascular shunt (perfusion pressure, mmHg)	ES flow mL/min (% PIS flow)	PIS flow mL/min
Introducer 6-F × 2 (90)	216 (64)	340
Introducer 8-F × 2 (90)	240 (73)	330
Introducer 6-F × 2 + 30 cm extension tube (90)	120 (36)	330
Introducer 8-F × 2 + 30 cm extension tube (90)	140 (45)	310

The inner diameter of the ES components was measured as follows: the sheath (Super Sheath®; Boston Scientific), 2.1 mm (6-F) and 2.9 mm (8-F); connector nipple for the sidearm, 1.8 mm; the side arm, 2.0 mm; three-way stopcock of the sidearm, 1.9 mm; Luer–Lock adapter (Combifix®; Braun), 2.4 mm. The inner diameter of the PIS was 2.0 mm. The total length of the ES and the PIS was 71 cm and 31 cm, respectively.

DISCUSSION

This study presents details of a novel technique for temporary arterial shunting to prevent ischemic injuries. The method can be used both to rapidly re-establish blood perfusion to ischemic tissues due to acute arterial obstruction, and also to avoid hypoperfusion during prolonged vascular interventions.

Occlusive vascular injuries in healthy individuals are prone to cause severe limb ischemia resulting in the need for hasty management. In addition, the clinical situation is often complicated by time delays such as in the transfer of patients from other hospitals, in diagnosis, and in preoperative preparations, further underlining the need for the immediate restoration of blood flow.[12] Therefore, prompt vascular reconstruction is of the highest priority, and the use of temporary shunts is recommended to shorten the ischemic time.[13]

Traditional shunting methods include open surgical exposure of the vessels, followed by intra-arterial positioning of the shunt.[5] This concept might be acceptable for injuries that are to be reconstructed by open surgery; however, in some patients with associated injuries and insufficient arterial mapping and in patients needing an endovascular reconstruction, open shunting may not be ideal. The ES technique presented herein enables rapid reperfusion of ischemic tissue without the need for open exposure. The method combines well with intraoperative angiography, even using the same introducer sheath. This means that an endovascular procedure for diagnosis or for definitive treatment can be performed in combination with the establishment of an ES, as described in this series. All cases of acute ischemia in this report were clinically severe. It is believed that the ES technique offers enhanced flexibility in the management of patients with acute, limb-threatening ischemia. Another advantage of the ES is that it is not necessary to occlude the inflow vessel to deviate the blood, as a traditional shunt does. Therefore, the inflow introducer can be positioned in an artery of a non-affected limb.

It is believed that this shunt method is well adapted for use during the transportation of patients. In two of the patients included in this study, the ESs were established in the radiology department followed by transportation of the patient with an active shunt to the operating theatre. Before transportation, skin sutures to prevent dislocation should be used to fix the introducers. Thus, the ES can be used as a damage control adjunct for vascular injuries in need of transportation to medical facilities of higher competence, as described by Chambers et al.[14]

It is also proposed that the ES can prevent ischemic complications during advanced endovascular aortic interventions. These interventions are associated with prolonged use of large diameter introducers. Severe lower limb ischemia after endovascular aortic procedures, such as complex fenestrated stent grafts, has been experienced. Four to five hours is considered to be the critical ischemic time for muscle tissue.[1] There may be hypoxic cellular damage followed by tissue reperfusion injury if flow interruption exceeds this limit. Furthermore, delayed limb reperfusion may cause negative systemic effects that may increase morbidity and mortality.[15,16] Recently, Constantinou et al.[11] reported a significant reduction in mortality after FEVAR when the lower limbs were perfused with a temporary axillobifemoral bypass. As it is difficult to predict injuries from ischemia–reperfusion, a proactive approach is recommended. The ES technique is easy to establish during endovascular procedures and most of the required material is readily available. The only additional item required is the male-to-male Luer–Lock adapter. The additional introducer, positioned antegrade in the CFA, adds little to the complexity and complication rate of the total procedure. It is therefore suggested that the ES should be used liberally when intraoperative hypoperfusion is expected.

In vitro flow measurement in this study demonstrated that the ES has a lower capacity than the PIS, which was believed to be due to the longer length of the ES together with the smaller inner diameter of the ES caused by the nipple to the side arm. Modification of the smallest inner diameter and the length of introducer sheaths could possibly increase the ES flow rate.

It is also believed that the further reduction in the intraoperative flow recordings compared with the experimental flow was due to the higher viscosity of the blood together with the lower pressure gradient over the shunt caused by the peripheral resistance present in vivo.

Commercially available shunts for open surgery differ widely in flow capacity owing to different inner diameters, and it should be noted that the PIS, which was the reference in this study, has a relatively low capacity compared with others.[17,18] However, the PIS is widely used in vascular surgery and its limited flow does not seem to be clinically important—at least not in carotid endarterectomy.[19] Is the flow capacity of the ES sufficient to prevent ischemic injury

to the lower extremities? It is believed that it is. Flow rates of 40–76 mL/minute were measured in three of the patients studied, and this level is probably enough to prevent ischemic injury, which is supported by the favorable outcome of all cases in this report. Besides, it can even be advantageous to have limited flow in initial reperfusion of severely ischemic tissues as this may limit the reperfusion injury.[20]

Caution is advised when shunting to high oxygen-demand tissue is needed, as the flow capacity of ES is limited. In such situations, it is suggested that the ES should be used only when established open shunt methods are not available. Limitations of this study include the retrospective, nonconsecutive design and the lack of a control group, particularly for the elective EVAR cases.

In conclusion, a new and simple method of temporary blood shunting using endovascular techniques has been presented. Preliminary outcomes are promising, but further studies are needed to determine the role of an ES in the elective setting.

FUNDING

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CONFLICT OF INTEREST

None.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejvs.2014.04.007.

REFERENCES

1 Blaisdell FW. The pathophysiology of skeletal muscle ischemia and the reperfusion syndrome: a review. *Cardiovasc Surg* 2002;**10**(6):620–30.
2 Eliason JL, Wakefield TW. Metabolic consequences of acute limb ischemia and their clinical implications. *Semin Vasc Surg* 2009;**22**(1):29–33.
3 Petrasek PF, Homer-Vanniasinkam S, Walker PM. Determinants of ischemic injury to skeletal muscle. *J Vasc Surg* 1994;**19**(4):623–31.
4 Rich NM, Baugh JH, Hughes CW. Acute arterial injuries in Vietnam: 1,000 cases. *J Trauma* 1970;**10**(5):359–69.
5 Eger M, Golcman L, Goldstein A, Hirsch M. The use of a temporary shunt in the management of arterial vascular injuries. *Surg Gynecol Obstet* 1971;**132**(1):67–70.
6 Mukherjee D, Inahara T. Another use of the shunt in vascular surgery. *Am J Surg* 1983;**146**(3):385–6.
7 Manning BJ, Agu O, Richards T, Ivancev K, Harris PL. Temporary axillobifemoral bypass as an adjunct to endovascular aneurysm repair using fenestrated stent grafts. *J Vasc Surg* 2011;**53**(3):867–9.
8 Jonsson T, Larzon T, Jansson K, Arfvidsson B, Norgren L. Limb ischemia after EVAR: an effect of the obstructing introducer? *J Endovasc Ther* 2008;**15**(6):695–701.
9 Movius 2nd HJ, Zuber WF, Gaspar MR. Carotid thromboendarterectomy. Technique and results. *Arch Surg* 1967;**94**(5):585–91.
10 Percival TJ, Rasmussen TE. Reperfusion strategies in the management of extremity vascular injury with ischaemia. *Br J Surg* 2012;**99**(Suppl. 1):66–74.
11 Constantinou J, Giannopoulos A, Cross J, Morgan-Rowe L, Agu O, Ivancev K. Temporary axillobifemoral bypass during fenestrated aortic aneurysm repair. *J Vasc Surg* 2012;**56**(6):1544–8.
12 Sriussadaporn S, Pak-art R. Temporary intravascular shunt in complex extremity vascular injuries. *J Trauma* 2002;**52**(6):1129–33.
13 Hossny A. Blunt popliteal artery injury with complete lower limb ischemia: is routine use of temporary intraluminal arterial shunt justified? *J Vasc Surg* 2004;**40**(1):61–6.
14 Chambers LW, Green DJ, Sample K, Gillingham BL, Rhee P, Brown C, et al. Tactical surgical intervention with temporary shunting of peripheral vascular trauma sustained during Operation Iraqi Freedom: one unit's experience. *J Trauma* 2006;**61**(4):824–30.
15 Yassin MM, Harkin DW, Barros D'Sa AA, Halliday MI, Rowlands BJ. Lower limb ischemia-reperfusion injury triggers a systemic inflammatory response and multiple organ dysfunction. *World J Surg* 2002;**26**(1):115–21.
16 Rowlands TE, Homer-Vanniasinkam S. Pro- and anti-inflammatory cytokine release in open versus endovascular repair of abdominal aortic aneurysm. *Br J Surg* 2001;**88**(10):1335–40.
17 Verkerke GJ, van den Dungen JJ, Meyer T, Rakhorst G. Flow analysis in vascular shunts that bypass the carotid artery. *Int J Artif Organs* 2001;**24**(9):636–41.
18 Grossi EA, Giangola G, Parish MA, Baumann FG, Riles TS, Spencer FC. Differences in carotid shunt flow rates and implications for cerebral blood flow. *Ann Vasc Surg* 1993;**7**(1):39–43.
19 Hayes PD, Vainas T, Hartley S, Thompson MM, London NJ, Bell PR, et al. The Pruitt-Inahara shunt maintains mean middle cerebral artery velocities within 10% of preoperative values during carotid endarterectomy. *J Vasc Surg* 2000;**32**(2):299–306.
20 Anderson RJ, Cambria R, Kerr J, Hobson 2nd RW. Sustained benefit of temporary limited reperfusion in skeletal muscle following ischemia. *J Surg Res* 1990;**49**(3):271–5.